TPF Observatory Simulation and Modeling

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1 Introduction

The Terrestrial Planet Finder interferometer, whether it is a structurally connected boom or a constellation of formation-flying satellites, must function in the demanding environs of an L2 orbit. It must operate in zero-gravity, high vacuum, and extreme temperatures with extreme sensitivity and utter reliability. Its 3-4 meter diameter mirrors will be mounted either on a 35 m structure, or on an array of individual formation-flying satellites with an overall length up to 150 m. It would be very difficult to test such large structures at high vacuum and low temperature on the ground, and is impossible to test them as a whole at zero-gravity here on Earth.

In order to have confidence that the chosen designs work, the systems must be modeled in detail. This modeling, from the virtual planetary photons striking the simulated mirrors to the algorithms which will reconstruct the planetary system, is the justification for the TPF Observatory Simulation. The Observatory Simulation will integrate the detailed subsystem models used by the designers into an end-to-end model.

This poster will show an overview of the Observatory Simulation, some of its results to date, and what we hope to accomplish with it.

2 Integrated Modeling

The Observatory Simulation will work within the framework of the next-generation Integrated Modeling of Optical Systems (IMOS), which will incorporate, within Matlab, the optical modeling capability of MACOS for optics, NASTRAN for structures, SINDA/FLUINT for thermal, and the built-in functions of Matlab for control systems. IMOS and MACOS are JPL-developed modeling tools.

By using models which are developed for design purposes, the modeling effort will leverage this work into the end-to-end model at minimal additional cost. The simulation will trace photons from accurate science models, through high-fidelity optical elements, which will be perturbed by structural, thermal, and other models to simulate the environment experienced by the system in operation. In this way, the performance of the observatory can be simulated at both micro (individual element changes), and macro (mission planning) levels.

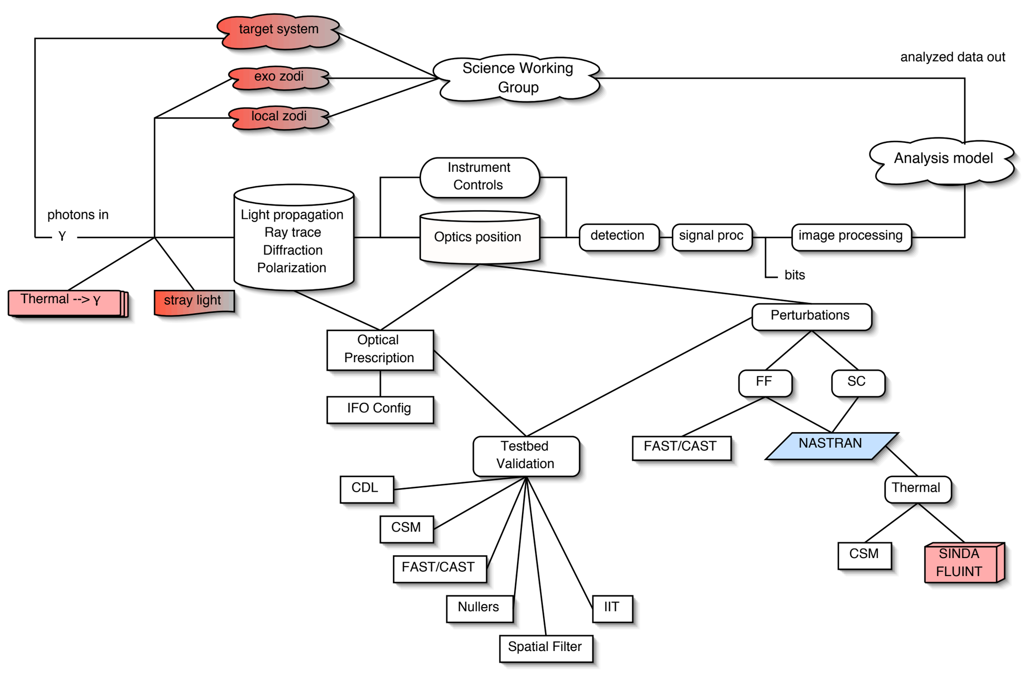


Figure 1: This diagram shows both the data flow of the model, and how the various models which are being developed at JPL for design work will be incorporated into the Observatory Simulation.

Figure 2 shows a ray trace through a representative high-fidelity optical model of the beam train. The interferometer simulation achieves an on-axis null (shown in Figure 4(a)) by an achromatic pupil rotation of 180 degrees in the periscopes. The consequence of the pupil rotation is that the polarization vector in one arm is rotated by 180 degrees with respect to the other arm for an on-axis source. The model achieves this by detailed ray tracing through the system, and by combining the simulated electric fields at the beam combiner.

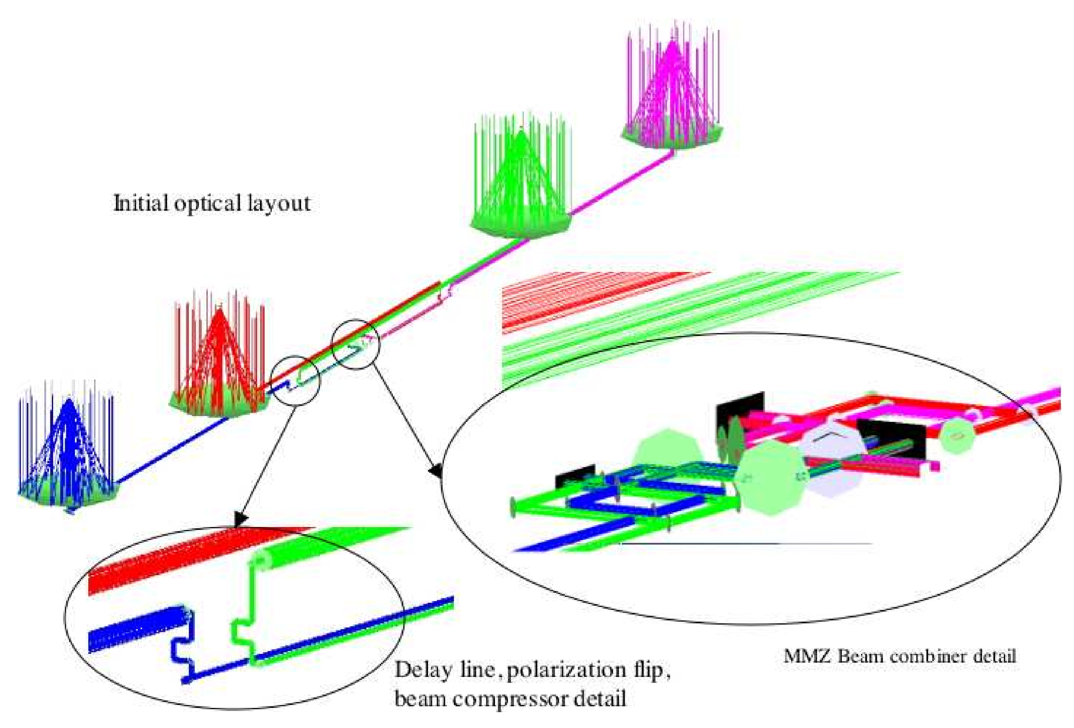
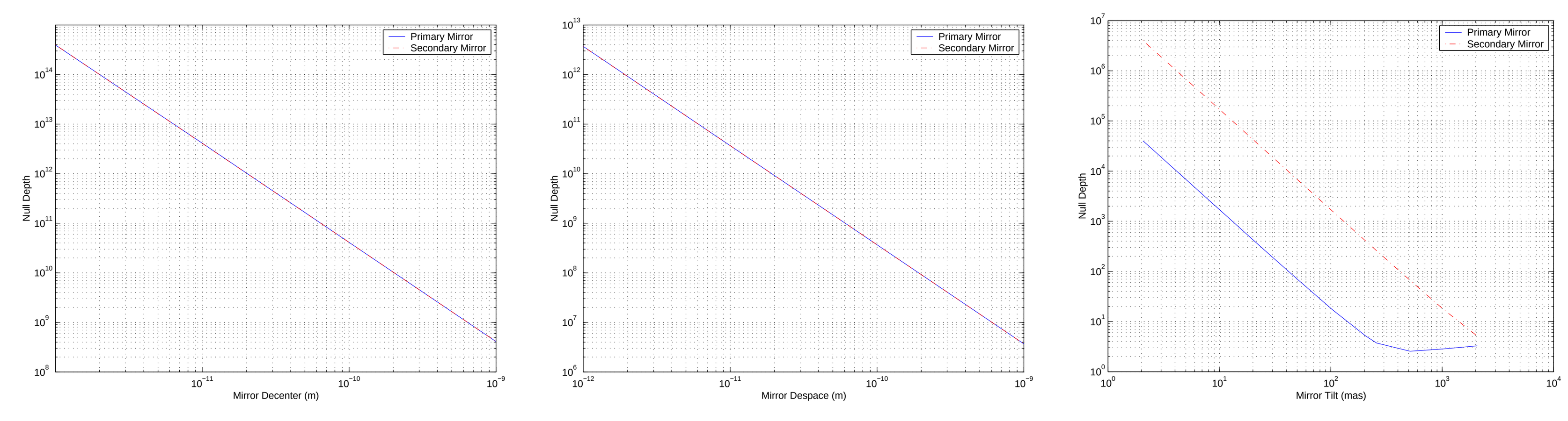


Figure 2: Detailed optical prescription of a proposed interferometer design.

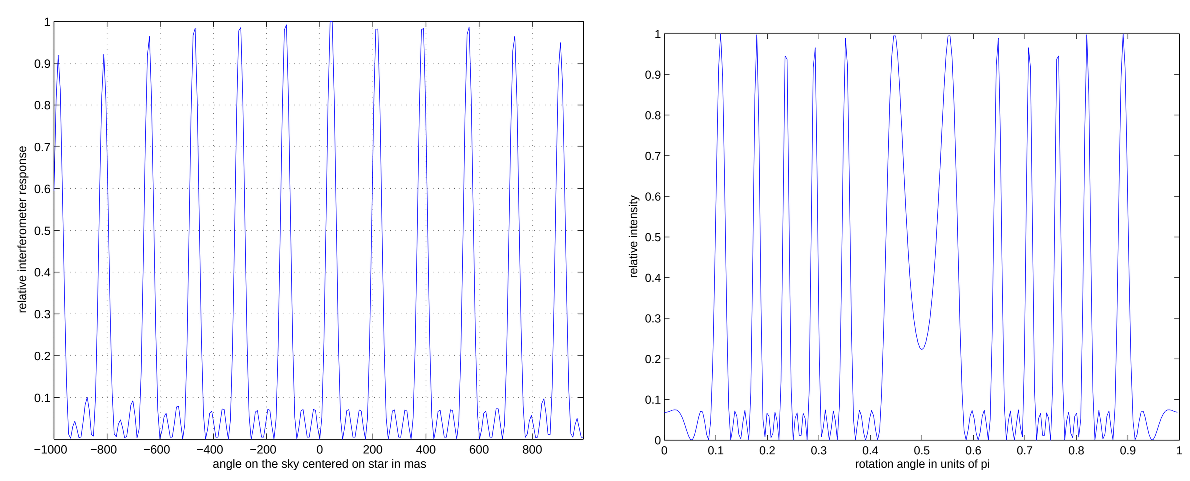
By perturbing each element in turn, the sensitivity of each element to a perturbation can be calculated. Figure 3(c) shows the sensitivity of the null depth to a decentering of the primary and secondary, a despace, and a tip/tilt. This calculation was done with no spatial filter and no control systems, which will reduce the sensitivity of the interferometer to these sorts of perturbations.



(a) Decenter (b) Despace (c) Tilt

Figure 3: Sensitivity calculations

By simulating the response of the interferometer to off-axis sources, the response versus angle on the sky can be plotted and validated against theoretical calculations (Figure 4(a)), and by rotating the interferometer with respect to an off-axis source, a time signal (Figure 4(b)) is generated which can be used to detect planets in orbit around another star.



(a) Interferometer beam pattern on the sky. (b) Planetary signal from rotating interferometer.

Figure 4:

The reconstructed signal below (Figure 5) was generated using algorithms based on Angel-Woolf [1] and Velusamy [2]. There is one planet in this simulation, with no noise. In this case, it's easy to see the planet (and its ghost opposite the star). When more planets are added, it becomes difficult to distinguish the artifacts of the reconstruction from planetary signals. Planetary reconstruction is an area in which much remains to be done.

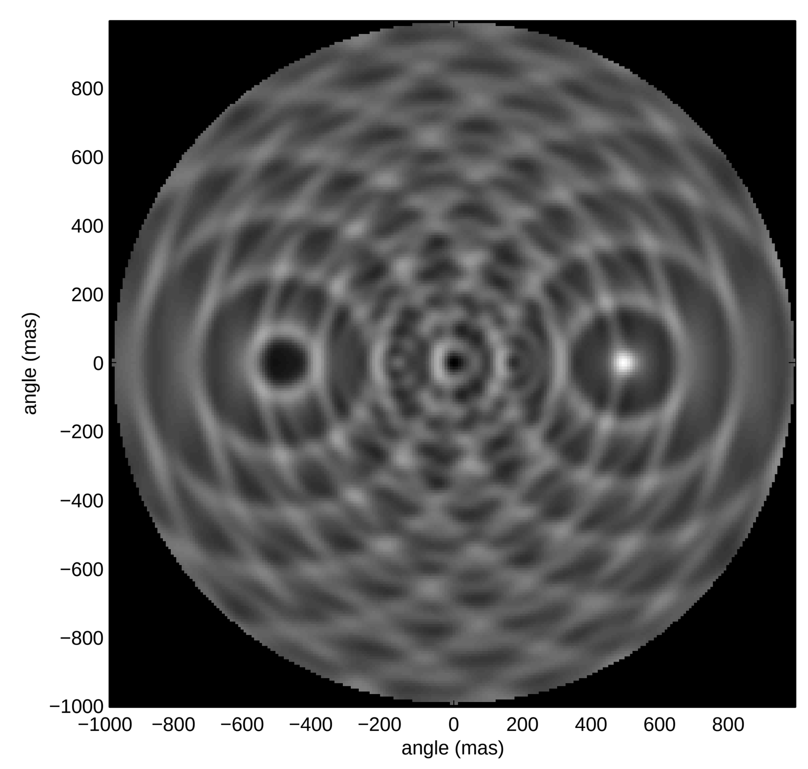


Figure 5: Reconstructed image from the planetary signal shown above.

References

[1] J.R.P. Angel and N.J. Woolf. An imaging nulling interferometer to study extrasolar planets. *Astrophys. J.*, 475:373, 1997.

[2] T. Velusamy and C.A. Beichman. Nulling interferometry for extra-solar planet detection - sensitivity and image reconstruction. In *Proceedings*, IEEE Aerospace Conference, Big Sky, MT,. IEEE, March 2001.

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